

A New Self-Aligned Technique for HBTs on GaAs Using Electrolytical Deposition of Base Metal

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Abstract

A new self-aligned process for base contacts in HBTs based on electrolytic metal deposition is presented. The goal of this technique is to simplify the processing, minimise the base series resistance and to metal-passivate the extrinsic base. Compatibility to a conventional HBT process is demonstrated. As an outlook a HBT structure with improved thermal properties, based on the presented technology, is proposed

Introduction:

To optimise the high frequency performance of HBTs various techniques for the placing of the base contacts have been developed [1]-[3]. Especially the self-aligned evaporation of the base metallisation where the emitter metal is employed as the evaporation mask, is an established technique for the fabrication of high frequency devices. This method usually leads to a separation between base metal and emitter edge, defined by the underetching of the emitter. The gap is generally in the order of some hundreds of nanometers. The paper will present a technique to relax the demands of this critical process. A new self-aligned process is presented, where basically no underetching is necessary. However to demonstrate the compatibility of this technique with standard technology, HBTs have been fabricated in a conventional way where only the process step for the base metallisation has been extended.

Electrolytic metal deposition

Electrolytic metal deposition in III-V technology is normally employed for the formation of air-bridges, via-holes, heat sinks etc. Since gold has a high thermal and electrical conductivity it is generally employed for this structures. Grüb [4] could show with an electrolytic fabricated platinum Schottky contact on GaAs for THz-mixer and varactor diodes the superior properties of this

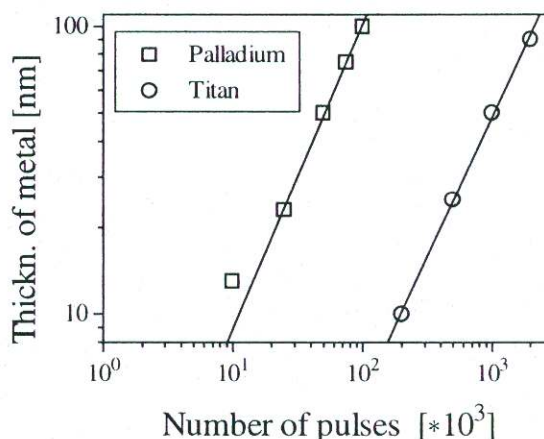


Figure 1 Thickness of deposited metal versus number of pulses.

devices compared to those fabricated with a conventional evaporation process. Besides the feature of a high quality semiconductor metal interface two other advantages are obtained with the electrolytic deposition technique compared to evaporation:

- Cost efficiency – only the needed material is consumed.
- “3d structures” – metallisation thickness of some micrometers are possible.
- Deposition of material in regions where evaporation is not possible.

The last property of electrolytic deposited metal is demonstrated in this paper.

The developed process for the deposition of palladium (Pd), titanium (Ti) and germanium (Ge) on GaAs is described in detail in [5]. In order to obtain best metal quality a pulsed deposition technique is employed. Fig. 1 shows the dependence of metal thickness on the number of applied voltage pulses. Very good linearity is obtained so that the metal-thickness can be controlled very precisely. The deviation for a small number of pulses Pd originates from the self-deposition property of this metal

Device Fabrication

For the fabrication of devices two wafers with the conventional HBT features have been employed: A 200nm thick n^+ -doped InGaAs cap layer for an easy emitter contact formation with Ti/Pt/Au on top of the wafer. Followed by a 400nm n -doped GaAs layer to allow the conventional self-aligned processing. For the emitter two different structures have been tested: A 50nm InGaP layer lattice matched to the GaAs base and a 50nm $\text{Al}_{0.38}\text{Ga}_{0.62}\text{As}$ emitter with a grading to the emitter cap side. The thickness of the GaAs base for both structures is 80nm, doped $4 \times 10^{19} \text{cm}^{-3}$. As in a conventional HBT

structure this layers were followed by n -doped collector layer and n^+ -subcollector.

The fabrication of our devices with $n \times 4 \times 20 \mu\text{m}^2$ emitterfingers ($n=1,2,4$), starts with the evaporation of a 400nm thick titanium emitter contact defined by a photoresist pattern. Followed by selective etching to the InGaP or AlGaAs emitter layer with an emitter undercut of approx. $0.5 \mu\text{m}$. The base contact area is subsequently defined by lithography employing a two layer photoresist technique.

The next step is the electrolytical deposition of the palladium base contact. Immediately before the deposition the samples are rinsed for two minutes in an $\text{HCl}:\text{H}_2\text{O} = 1:1$ solution in order to remove the native oxides. Then the 50nm thick Palladium layer is deposited with electrical pulses. Since the emitter base diode provides a voltage drop during the deposition pulse, there is strongly reduced metal deposition on the sidewall of the emitter. Without removing the photoresist the standard Ti/Pt/Au base contact is then evaporated. Fig 2(a) shows the sketch of the principle structure and fig. 2(b) a SEM picture of a HBT before the evaporation of the base contact. The photoresist has been removed.

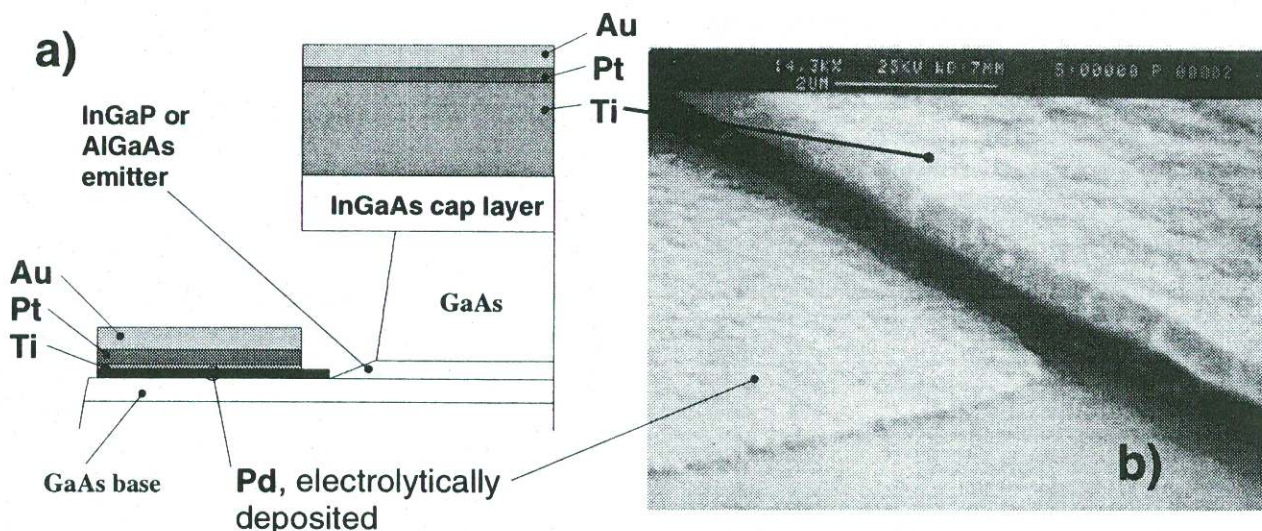


Figure 2 (a) Schematic sketch explaining the developed process (b) test structure after the electrolytical deposition of Palladium.

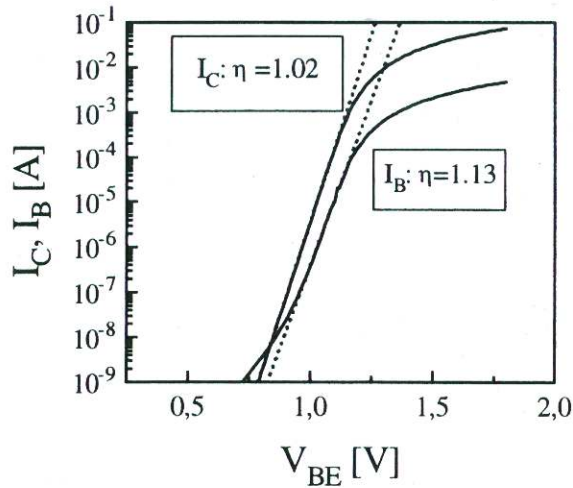


Figure 3 Gummelplot of a fabricated GaInP/GaAs HBT.

The subsequent fabrication steps include base mesa and device isolation etching, collector contact evaporation and plating of air-bridges for contacting the device to a coplanar structure for on wafer rf characterisation.

Electrical characteristics

The typical Gummelplot of a fabricated InGaP/GaAs device is shown in Fig. 3. The focus should be oriented towards the ideality factor $\eta=1.1$ of the base current. Similar results have been obtained for the HBT with AlGaAs emitter where a base current ideality factor of 1.3 has been measured. The point where base and collector current are equal is for both materials in the order of some nanoamperes. These low values for the ideality factors are generally attributed to an unpassivated external base layer [6],[7] origin from the low influence of the "natural surface". However a completely metal covered external base is also expected to show a comparable performance.

The measured influence on high frequency performance is shown in Fig. 4. The plot shows a comparison for f_{\max} between an AlGaAs/GaAs transistor from the standard process and a HBT with additionally electrolytically deposited base contact. The transistor from standard process showed lower f_T for equal I_C , originating from process related variations on the specific contact resistance for the emitter metal. To compare performance of the transistors the bias currents have been chosen to obtain a

$f_T \approx 20\text{GHz}$ for each device, leading to a higher collector current for the device from the standard process. This results in a higher MAG-value for frequencies lower 2GHz. From the relation

$$f_{\max} = \sqrt{\frac{f_T}{8 \cdot \pi \cdot R_B \cdot C_{BC}}}$$

a reduction of base access resistance R_B of more than 50% can be calculated. This strong decrease originates from two different effects:

- reduction of base access resistance with electrolytically deposited base contact.
- reduction of base contact resistance with palladium contact in comparison to titanium contact.

Outlook

The presented results show the possibility to have a self-aligned process even under the emitter metallisation. Figure 5 shows a sketch of a HBT structure with improved thermal properties based on the developed technology. The idea behind this structure is the heat transport out of the device through the emitter air bridge. As shown by [8] this requires very thick air-bridge metallisations and a direct contact of the plated metal along the whole emitter finger. For good high frequency performance the emitter width should be minimal. These two requirements are contradictory.

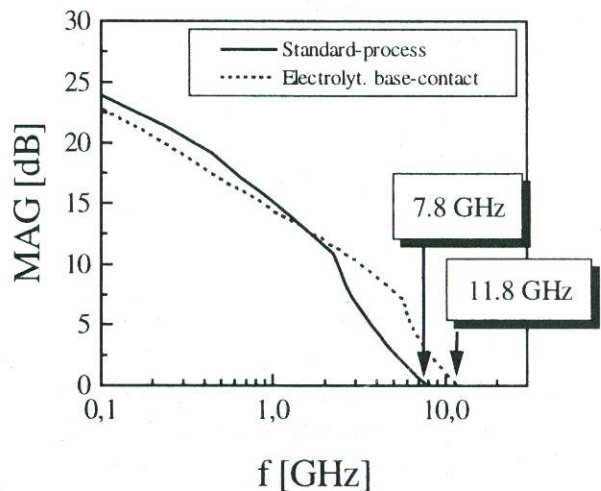


Figure 4 Comparison between MAG of HBTs from standard process and with electrolytically deposited base contacts ($V_{CB}=6\text{V}$; $I_C \approx 6\text{mA}$). To avoid thermal effects not the maximum operating current has been chosen.

Employing the developed technology a small emitter can be used, which is contacted by a plated T-shaped emitter contact. The T-shaped emitter contact ensures a large contact area for the air bridge and therefore relaxing the demands on technology. Self-aligned base contact is fabricated by a plated base contact without the requirements of a overhanging emitter structure. This allows the minimisation of the emitter thickness, improving further the thermal properties.

Conclusion

A method for the electrolytical self-aligned deposition of the base contact for GaAs based HBT is demonstrated. This technique allows the minimisation of base series resistance in order to optimise the rf performance and a metal passivation of the extrinsic base. Additionally the emitter underetching process is simplified because the electrical separation between base metal and emitter edge is automatically obtained by the potential drop over the emitter base diode during deposition procedure.

Based on the developed technology a modified HBT structure is proposed. This structure is intended to have improved thermal properties.

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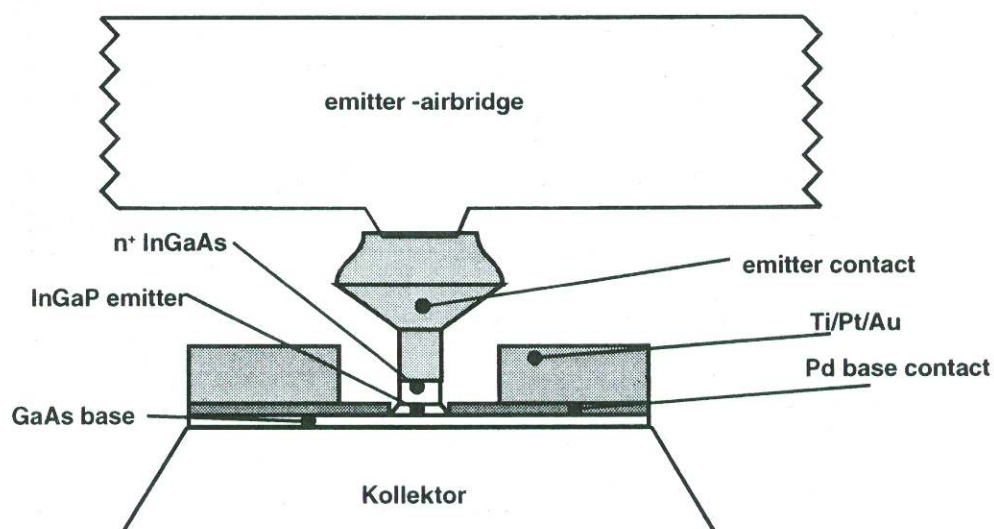


Figure 5 Cross section of a HBT with improved thermal properties